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Motion-Compensated Adaptive Dual Tree Complex Wavelet Transform Coding for Scalable Color Video Compression using SPIHT

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ABSTRACT

Video compression plays a vital part in many digital video processing for applications such as digital video transmission, also thousands of websites like YouTube, Netflix etc. that requires large storage space. Video compression technologies are about reducing and removing redundant video data so that a digital video file can be effectively sent over a network or can be put in storage on computer disks with the reduction of data size. In this research paper video compression using motion compensation technique that reduces video data based on motion estimation from one frame to another, is proposed. Diamond Search (DS) motion compensation is an algorithmic technique employed for the encoding of video data for video compression. Motion compensation vectors describe a frame in terms of the transformation of a reference frame with respect to the current frame. The reference frame may be previous in time or even from the future. The proposed method reduces the searching of compression portion based on DS Algorithm in temporal redundancy video sequences. Motion blocks are further compressed by using the Scalable Video Compression methods, Adaptive Dual Tree Complex Wavelet Transform (ADT-CWT) and SPIHT. The performance of the proposed methodology is evaluated in terms of the peak signal-to-noise ratio (PSNR) and the compression ratio (CR).

Keywords: Scalable Video Compression (SVC), Diamond Search (DS), ADT-CWT, SPIHT.

1. INTRODUCTION

The storage and transmission of image and video data are taking forward the development of new compression methods in this digital world. By sacrificing the quality of the image and video content, the compression efficiency is achieved in widely used international standards such as JPEG [1], JPEG-2000 [2], H.264 [3] and MPEG-4 [4]. The conservation of the original data is more important than compression efficiency in applications which include storage and transmission of medical and satellite images which is the area of lossless compression [5]. In live video transmission, compression plays important role because these video frames not require detailed information like tumor, nerves etc.

In color video sequences, spatial, spectral and temporal redundancy is three types of major redundancies. Spatial redundancy occurs among neighboring pixels in a frame. Usually in a frame, the pixel values do not change abruptly except near edges and highly textured areas. Hence among neighboring pixels there is significant correlation, which can be used to predict pixel values in a frame from nearby pixels. To obtain an error or a residual, the predicted pixel is subtracted from the current pixel. The resulting residual frame has significantly lower entropy comparatively. Lossless JPEG which is obtained by linear combination of

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neighboring pixels uses simple linear predictors. CALIC [6] uses prediction by a nonlinear gradient. MED (Median Edge Detector) prediction is used in JPEG-LS which can detect edges in neighboring pixels.

During video compression, generally spatial and temporal redundancy methodologies are used to compress the video frame. Spatial redundancy uses lossless compression and hence it fails to achieve compression efficiency. Whereas temporal redundancy uses lossy compression, which gives better compression efficiency than spatial redundancy. By temporal prediction, temporal redundancies between frames can be removed. In lossy compression, block based temporal prediction by motion compensation provides very high coding gain where the technique de-correlates the frames. Motion vectors which are required to reconstruct the frame are transmitted as overhead data. The performance obtained using block based motion compensation is not as effective as obtained in the case of lossy compression [8]. In addition to spatial and spectral correlation, several techniques utilizing temporal correlation have been described previously [7], [8].

Temporal prediction does not work well in this case and only spatial prediction can be used. In static areas where little motion has occurred between frames, temporal prediction works better than spatial prediction. If one could use adaptive selection of the prediction technique, it would seem logical that one may be able to increase the coding efficiency. For an image and video compression, the wavelet transform has been used as a successful tool. One most important property of the wavelet transform for compression applications is energy compaction. After the wavelet transform, most of the energy in the original image is compacted into the coarsest sub band. The other 3 finer sub bands have high frequency components of the original image and many wavelet coefficients in these sub bands are small in magnitude [9]. The prediction techniques utilizing three redundancies (spatial, spectral and temporal redundancies) does not perform satisfactorily, since the wavelet coefficients in the finer sub bands are less correlated with each other. However, the wavelet coefficients in the coarsest sub band are highly correlated each other and prediction techniques can remove the redundancies efficiently. Usually, the wavelet transform generates floating-point values, which means the operation is not reversible, although the original image can be recovered by the use of perfect reconstruction filters in principle. In lossless compression, the complete recovery of the original pixel values is required.

In signal and image processing, Traditional Wavelet analysis is a powerful tool, and it gained over the Fourier transform because of its time frequency localization. It is being preferred in many applications from signal and image compression to image de-noising and even communications. Discrete Wavelet Transform is the most compact and is the most common form. It offers a high flexibility in implementation, offering the possibility of using a wide number of wavelet families, due to its filter-bank implementation. In addition to all the benefits of this transform, it also has many limitations such as its shift-sensitivity and its poor directional selectivity. By using some of DWT’s extensions, we can partially overcome these limitations, such as the UDWT which is translation invariant or the Discrete Wavelet Packet Transform that offers a better directional selectivity. The use of complex mother wavelets, or complex wavelet transforms is an alternative way to overcome these limitations. Another way an IWT (Integer Wavelet Transform), which maps integer pixels to integer coefficients, can be used [10], [11], [12], [13]. Without any loss, the IWT can recover the original values of the image. It is shown that by the lifting scheme an integer version of any floating-point wavelet transform can be obtained [14], [15]. The performance of the IWT highly determined by the content of the image and video and the wavelet filter used.

2. LITERATURE REVIEW

In paper [16], the authors have presented a video compression algorithm that generates a layered bit stream that can be decoded at different quality levels depending on the amount of resources available to the decoder in terms of computational capacity, network bandwidth and visualization abilities. They have proposed an algorithm called as EZWTP, which has been designed with the scalability and real-time properties as a primary requirement, and even tried to maintain high compression efficiency and low computational complexity. They have achieved low computational complexity by eliminating motion compensation. The motive for doing so is that the target application (Internet videoconferencing) denotes that a reasonably low-motion video content can be assumed. The inter-frame compression of EZWTP has been shown to give a substantial compression performance for low-motion video scenes. They have shown that the EZWTP codec exhibit competitive compression performance for high-resolution video, due to the superior spatial de-correlation properties of the wavelet transform compared to the discrete cosine transform. For lower resolution video, non-scalable codecs with motion compensation typically outperform the EZWTP algorithm. However, they are comparing alternative frames for motion compensation, and hence it increases the delay. The complexity will increase; in case the numbers of video frames are increased in a particular time interval (fps).

In paper [17], the authors have proposed a new algorithm called as adaptive leakage predictors FGS (ALF.FGS). The ALF.FGS is not only well adapted to fluctuations in network bandwidth, but also provides greater flexibility to the macro block encoded video frame based on motion characteristics and texture characteristics of adaptive selecting a different reference macro block. Their experimental result has shown that the ALF.FGS algorithm can effectively eliminate error at low bit rate and enhance the FGS coding efficiency. However, they have used macro block which is fixed block to find the motion compensation vectors. Moreover, during encoding and decoding unwanted frames are discarded and again going with re-encoding it increases time complexity.

In paper [18], the authors have proposed combination of scalable video coding (SVC) and bit division multiplexing (BDM) and they have implemented for scalable video broadcasting (SVB). They have shown that, compared with time division modulation, SVB using BDM can attain high spectral efficiency, whereas compared with conventional hierarchical modulation, SVB using BDM resolves the problem of flexibility limitation. Moreover, simplified BDM technique, BDM-Lite has been proposed to assure about the robustness and low complexity of baseline layer reception, which is especially suitable for receiver with computing and hardware resources, such as mobile/handheld receivers. However, the study has considered only standard resolution videos for testing. The study has not considered about the higher resolution videos. This paper fails to prove the effect of proposed methodology when the input is higher resolution video.

In paper [19], the authors have proposed an effective algorithm for macro block-level rate control to solve the problem of strong rate variation when scene structure and its motion abruptly change. For this, they have presented a new adaptive rate control mechanism for H.264 to produce a more stable output video stream, given a bursty video sequence as the input, avoiding the possible buffer overflow and quality decrement on the way of video streaming over networks. Their results show that their technique can yield a more stable bit-rate than JM, the current method used in H.264/AVC, but maintain similar video quality as JM in the high motion cases. Their proposed technique provides more constant video quality to user and helps the network manager to allocate bandwidth more efficiently. However, the comparisons between the proposed and existing algorithms are based on PSNR, number of frames and packet error rates. The study has not considered compression ratio and motion compensation searching point.

In paper [20], the authors propose a low complex Scalable ACC-DCT based video compression approach which tends to hard exploit the pertinent temporal redundancy in the video frames to improve compression efficiency with less processing complexity. However, fixed point 2D DCT (8 point) compression has been used here to compress image to reduce power consumption. But fixed method increases complexity in both hardware and software when video frame size increased.

In paper [21], the authors have proposed an innovative video compression technique using DWT-DCT. They have introduced advancement in the video compression technology to enhance the compression ratio, without losing much quality of the video. They have introduced the method which is simple to implement in the practical implementation and with small amount of modification in the existing codec gives better result. However, the proposed method is based on two low frequency domain compression. These kind of compression gives scrambling effect at receiver side.

In paper [22], the authors have proposed a new video codec using the novel3-D Dual-tree wavelet transform hybrid with Particle Swarm Optimization (PSO) and they have tested on standard video sequences foreman and Rhinos. The DDWT-PSO video codec applies adaptive vector arithmetic coding across sub-bands to efficiently code the significance bits jointly. At the time of coding the sub bands, the optimal sub bands are chosen by using the PSO algorithm. The proposed video codec does not require motion compensation and provides better performance than the 3D SPIHT (Embedded type) codec, both objectively and subjectively, and the coder allows full scalability in spatial, temporal and quality dimensions. However, they consider whole video frame for encoding and they used PSO for selecting optimal sub bands in low and high sub bands. During encoding PSO does not have any termination threshold to find best sub bands from existing coefficients.

In paper [23], the authors have proposed an efficient fine-granular scalable (FGS) coding algorithm to compress 3D mesh sequences in low-latency streaming applications. To support the finest-granular spatial scalability, they have destroyed only a single vertex at each layer to obtain the next coarser layer. During the spatial layer decomposition, they have tried to obtain high quality intermediate resolution meshes by exploiting the topological and geometrical relationship between vertices. Also, they have adopted a hierarchical prediction structure to support temporal scalability. Then, they have predicted each vertex position spatially and temporally, and encode those prediction residuals efficiently using a context-based binary arithmetic coder. They have shown that the proposed algorithm can reduce bit rates by about 30% and 20%, as compared with SPC and the Bici and Akar’s algorithm, whereas supporting much finer-granular spatial scalability. However, the study has used multiple layer decomposition special and temporal prediction is used to find bit stream. During the time of decomposition, the information about vertices is not passed to all frames.

In paper [24], the authors have introduced a more computationally efficient approach to shift invariance, the dual-tree complex wavelet transform (DT-CWT). Moreover, the proposed DT-CWT gives much better directional selectivity when filtering multi-dimensional signals. They have shown that the dual tree complex wavelet transform (DT-CWT) yields improved PSNR and the definition of reconstruction image compared to those obtained from discrete wavelet transform (DWT).

3. PROPOSED METHODOLOGY

In this paper, a video compression scheme based on the Adaptive Dual Tree Complex Wavelet Transform (ADT-CWT) representation and motion compensation is presented. For representing images and video signals, the multi-resolution/ multi-frequency nature of the standard discrete wavelet transform is an ideal tool. In the multi-resolution motion compensation approach, motion vectors in higher resolution are predicted by large pattern diamond search (LPDS) for fast block matching the motion vectors in the lower resolution are predicted by small pattern diamond search(SPDS) refined at each step. A method based on variable block-size motion compensation scheme in which the size of a block is adjusted to its size of input video frame in this paper, has been proposed. This scheme gives a significant portrayal of the intrinsic motion structure and also impressively lessens the searching and matching time. After wavelet decomposition, each scaled sub-frame has a tendency to have distinctive statistical properties. Every motion frames are encoded and decoded using SPIHT encoder and decoder. An adaptive truncation process is implemented and a bit allocation scheme similar to that in the transform coding is inspected by adapting to the local variance distribution in each scaled sub-frame. The block diagram of proposed method is shown in figure.1.

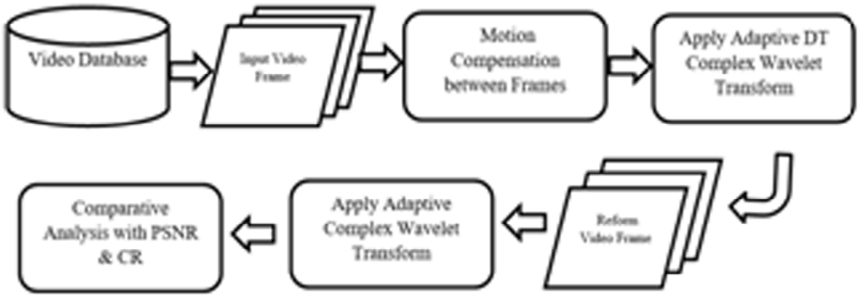

Figure 1: Block diagram for Motion-Compensated Adaptive Dual Tree Complex Wavelet Transform Coding for Scalable Color Video Compression

3.1. Diamond Search Algorithm

DS algorithm is similar like four-step search (4SS) algorithm, but the pattern for search point is altered from a square to a diamond, and there is no restriction on the number of steps taken by the algorithm. Two different sorts of fixed search patterns use by the DS algorithm. The first pattern named as large diamond search pattern (LDSP) presented in Figure 2 and the second pattern named as small diamond search pattern (SDSP) presented in Figure 3. The LDSP comprising of nine checking points, in which eight points surround the center point to form a diamond outline. The SDSP comprising of five checking points those create a smaller diamond outline.

The searching method for the DS algorithm is demonstrated in Figure 4. The first step utilizes LDSP and if the minimum block distortion (MBD) happens at the center point then jump to last step. The subsequent

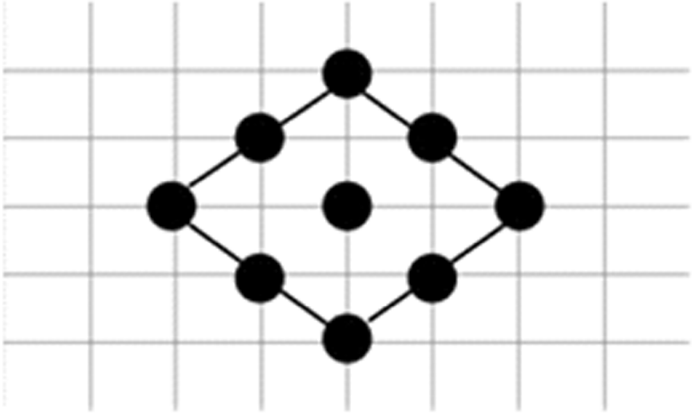

Figure 2: Large Diamond Search Pattern (LDSP)

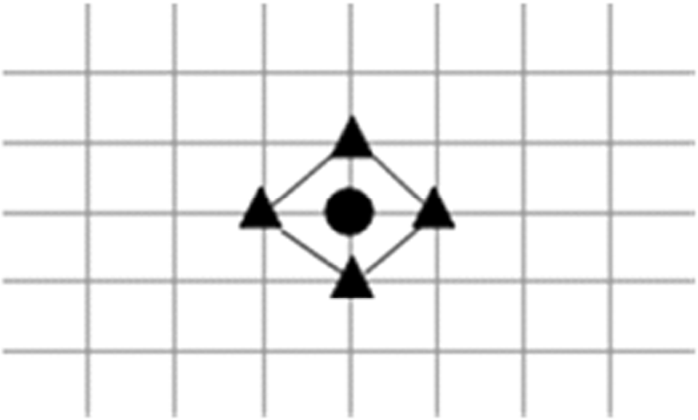

Figure 3: Small Diamond Search Pattern (SDSP)

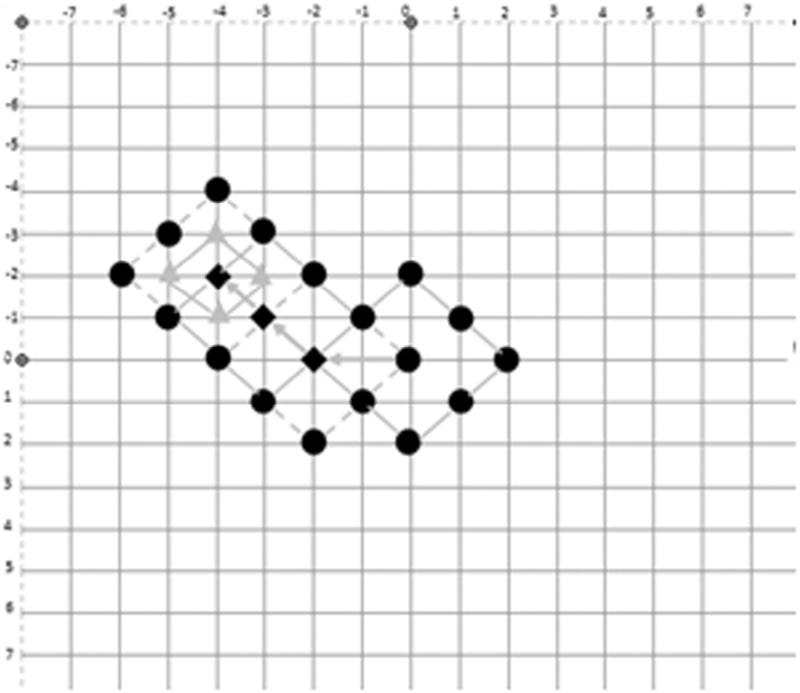

Figure 4: Search path example to the motion vector (-4,-2) in five search steps—four times of LDSP and one time

step, aside from the last step, use LDSP, is recurrently utilized till the step in which the minimum block distortion (MBD) happens at the center point.

In the last step, search pattern is changed from LDSP to SDSP to figure out the MBD point. Among the five checking points in SDSP, the MBD point found in this stage delivers the final result motion vector of the best matching block. DS is one of the most renowned fast motion estimation algorithm consistently performs well for the image sequence with wide range of motion content. It additionally surpasses the well-recognized three-step search (TSS) algorithm and accomplishes close MSE performance contrasted with new three-step search (NTSS) algorithm while decreasing computation by 22% roughly.

After completion of diamond search, the motion between the determined video frames gives motion vectors. These vectors contain rapid pixel changes or high motion portion between the consecutive frames. Then, APIHT method has been applied on highly motion blocks. After that ADT-CWT has been applied on the whole frame.

3.2. Adaptive Dual Tree Complex Wavelet Transform (ADT-CWT)

Complex Wavelets Transforms (CWT) use complex-valued filtering (analytic filter) that decomposes the real/complex signals into real and imaginary parts in transform domain. The real and imaginary coefficients are used to compute amplitude and phase information, just the type of information needed to accurately describe the energy localization of oscillating functions (wavelet basis). Edges and other singularities in signal processing applications manifest them as oscillating coefficients in the wavelet domain. The amplitude of these coefficients describes the strength of the singularity while the phase indicates the location of singularity. After getting motion blocks from DS algorithm, SPIHT has been applied for each.

3.2.1. Set partitioning in hierarchical trees (SPIHT) encoder and decoder

Wavelet-based image encoding algorithms significantly enhance the rate of compression and the visual quality, many research propose numerous different techniques for encoding the images based on wavelet.

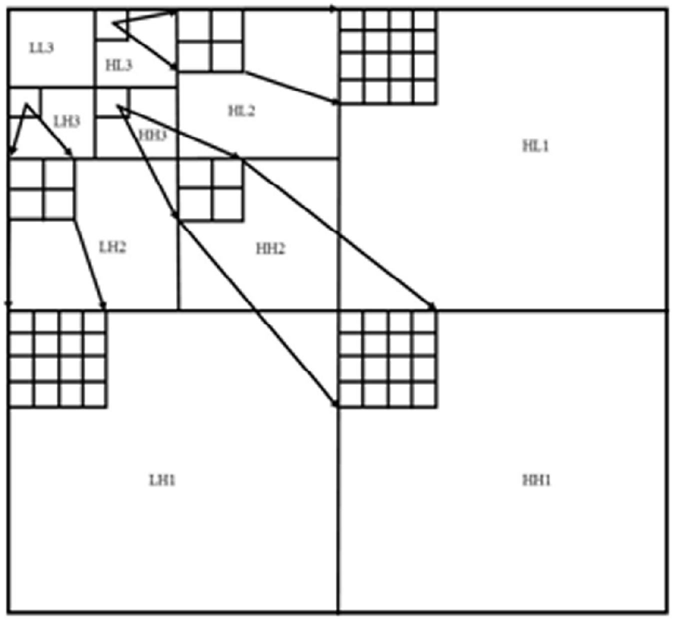

Figure 5: Parent–child relationship

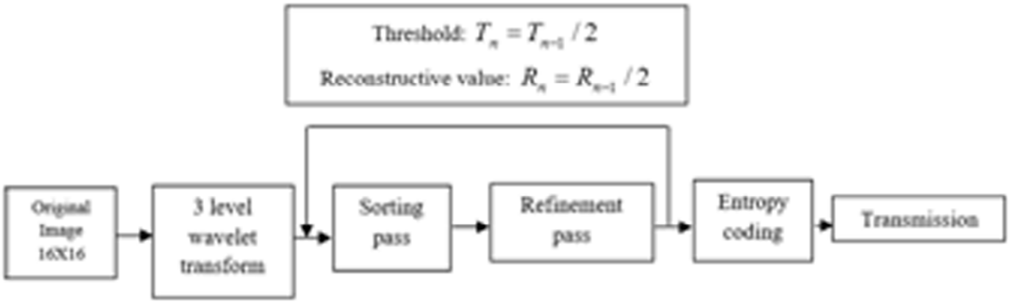

Figure 6: Flowchart of SPIHT

The SPIHT algorithm is an effective technique for lossy, as well as for lossless coding of natural images. The SPIHT algorithm implements a hierarchical quad-tree data structure on wavelet-transformed image. A wavelet-transformed image’s energy is concentrated on the lower frequency coefficients. A tree structure, named as the spatial orientation tree (SOT), actually characterizes as the spatial relationship of the hierarchical pyramid. Fig. 5 exhibits how a spatial orientation tree is characterized in a constructed like a pyramid with recursive four sub-bands splitting. The coefficients are arranged in hierarchies. According to this relationship, the SPIHT algorithm saves a lot of bits that determine insignificant coefficients. High motion block size is considered as 16x16. N number of motion blocks obtained after extracting the motion blocks from Ith frame, and each motion blocks are considered as a separate frame for encoding. Adaptive threshold has been applied on every motion block based on mean value of pixel to compensate decomposition level.

The flowchart of SPIHT algorithm has been exhibited in Fig. 6. In the first stage, the original image is decomposed into 10 sub-bands. At that point the technique finds the maximum and the iteration number. In the second stage, the technique places the DWT coefficients into sorting pass that finds the significance coefficients in all coefficients and encodes the sign of these significant coefficients. In the third step, the significant coefficients are placed into the refinement pass that use two bits to exact the reconstruct value for closing to real value. The front, second and third steps are iterative, next iteration decreases the threshold $T_n = T_{n-1}/2$ and the reconstructive value $R_n = R_{n-1}/2$. Next step, the encoding bits access entropy coding and then transmits.

The rate of compression and the visual quality has been enhanced due to wavelet-based-image encoding algorithms. But, there is a drawback of the wavelet-transform computation algorithms. One research work found that methods based on wavelet, for example, SPIHT are subjectively better to JPEG compressed at a moderately high bit rate. On the other hand, SPIHT develop ringing artifacts with compression ratios above 12:1 (bit rate < 0.67 bpp), affecting diagnostic acceptability. Images which are coded at medium bit rate, experience the effect of loss of detail and sharpness, and additionally different coding artifacts. One of the coding artifacts is ringing which appears as small ripples around the edge of the image. So, we avoid to apply SPIHT to full frames, it may increase the ripples on the images. Our technique is to split full frame into 16x16 blocks based on the motion present in the frame and it significantly avoids ripples in frames. After completing, SPIHT compressed blocks are replaced in their own place and it move to spatial decomposition of frame using DT-CWT.

3.2.2. Dual tree complex wavelet transform

The dual-tree complex wavelet transform utilizes two real DWTs. These two transforms together provide an overall transform. The first DWT transform point toward the real part and the second transform point toward the imaginary part. The two real wavelets incorporated with each of the two real wavelet transforms are represented as $\psi_i(s)$ and $\psi_j(s)$. After the filters are generated, the complex wavelet is roughly estimated as follows:

$$\psi(s) = \psi_j(s) + j\psi_j(s) \tag{1}$$

In the dual-tree complex wavelet transform, wavelet function $\psi(a, b) = \psi(a)\psi(b)$ is incorporated with the row column of the wavelet transform, where $\psi(a)$ is a complex wavelet represented by $\psi(a) = \psi_i(a) + j\psi_j(a) \bullet \psi(a,b)$ is achieved from the equation:

$$\begin{aligned}\psi(a,b) &= [\psi_i(a) + j\psi_j(a)][\psi_i(b) + j\psi_j(b)] \\ &= \psi_i(a)\psi_i(b) - \psi_j(a)\psi_j(b) \\ &\quad + j[\psi_j(a)\psi_i(b) + \psi_i(a)\psi_j(b)]\end{aligned} \tag{2}$$

The real part of the complex wavelet is taken, and then the sums of two separable wavelets are obtained:

Real Part $$\{\psi_i(a,b)\} = \psi_i(a)\psi_i(b) - \psi_j(a)\psi_j(b) \tag{3}$$

A directional filter of DTCWT is applied on the frame for decomposition purposes. The resultant images are the output of the one directional filter from the low pass and high pass filters. The DTCWT coefficients that are achieved from the first filter bank are known as the real part and the coefficients that are achieved from the other filter are known as the imaginary part. The real part of the image contains less significant data in comparison with the imaginary part which comprises of more information. In each comparison of motion, we have obtained an initial frame or I-frame and it is taken for DTCWT decomposition. Before decomposition it is necessary to encode and decode the high motion estimated region using SPIHT. DT-CWT is applied to full size of frame after encoding of blocks using the adaptive method and SPIHT.

4. EXPERIMENTAL SETUP AND DISCUSSION

This Simulation was developed in Matlab platform. The basic system requirements are Intel 2.66GHz i3 processor, 4 GB RAM and Matlab version 8.0.0.783 software is require to run this simulation. We compare the block-based motion model with the Exhaustive Search of the temporal transform. We use the first 25 frames of the standard test sequences, “viptraffic” and “xylophone”. The original sequences have a frame rate of 30 fps and a spatial resolution of 352 × 240. The block-based model is implemented using a diamond search method. A motion field is first estimated by full-search block matching at half the spatial resolution. The search range is relative to the temporal displacement of +/- 8 pixels per frame.

The successive frames are taken to estimate motion. The block size is 16x16, giving 300 motion vectors per field. We form the regular Exhaustive Search by dividing 16 × 16 blocks. Motion vectors are estimated for each node in the frame, resulting in 300 vectors per motion mapping. The proposed motion based

Table 1
Performance comparison for Xylophone video

	Xylophone											
	Diamond Search						*Exhaustive Search*					
	PSNR			*CR*			*PSNR*			*CR*		
Frames	*Excising*	*Without Adaptive*	*Proposed*	*Excising*	*Without Adaptive*	*Proposed*	*Excising*	*Without Adaptive*	*Proposed*	*Excising*	*Without Adaptive*	*Proposed*
Fram 1	41.8185	33.5936	33.0921	0.9931	0.9667	0.9664	41.8185	33.5936	33.0921	0.9931	0.9668	0.9664
Fram 2	40.3642	33.6271	32.9776	0.9950	0.9465	0.9455	40.3642	33.6271	32.9776	0.9950	0.9465	0.9455
Fram 3	40.6844	33.6584	33.0349	0.9918	0.9547	0.9525	40.6844	33.6584	33.0349	0.9918	0.9547	0.9526
Fram 4	41.1215	33.6544	33.0783	0.9950	0.9494	0.9475	41.1215	33.6544	33.0783	0.9950	0.9494	0.9475
Fram 5	40.8901	33.6474	33.0774	0.9931	0.9484	0.9472	40.8901	33.6474	33.0774	0.9931	0.9485	0.9473

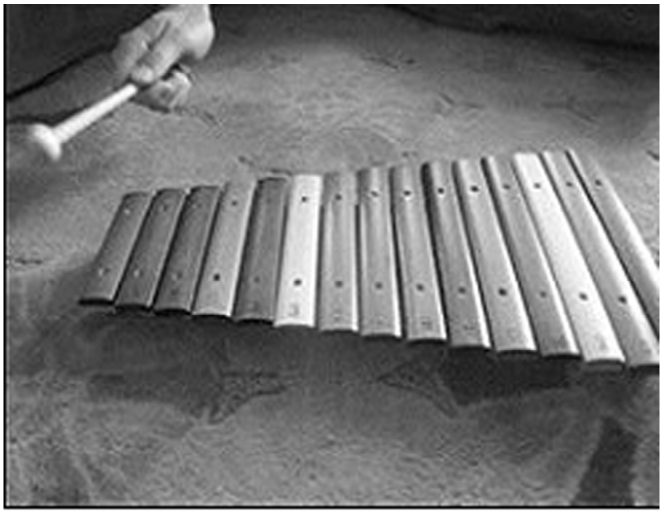

Figure 7: Input Image

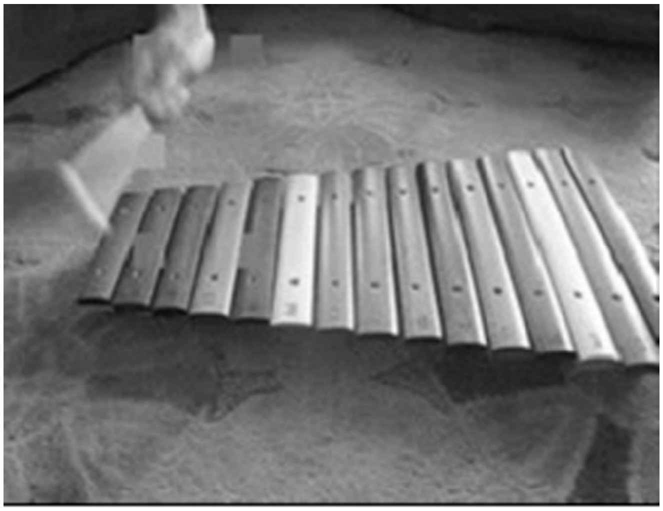

Figure 8: Existing Image

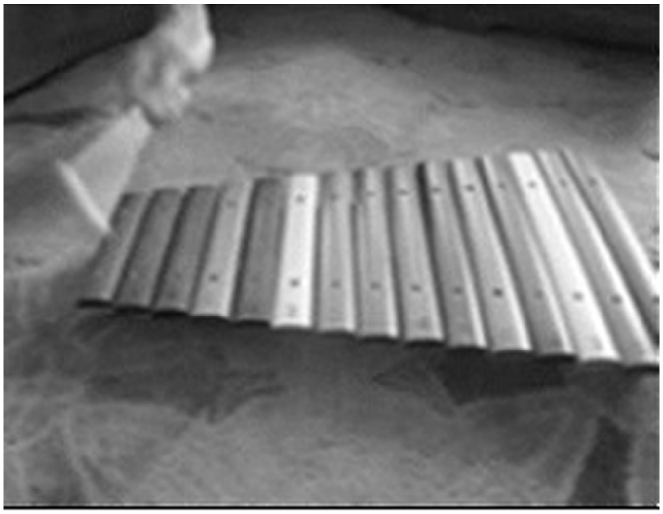

Figure 9: Proposed without Adaptive Method

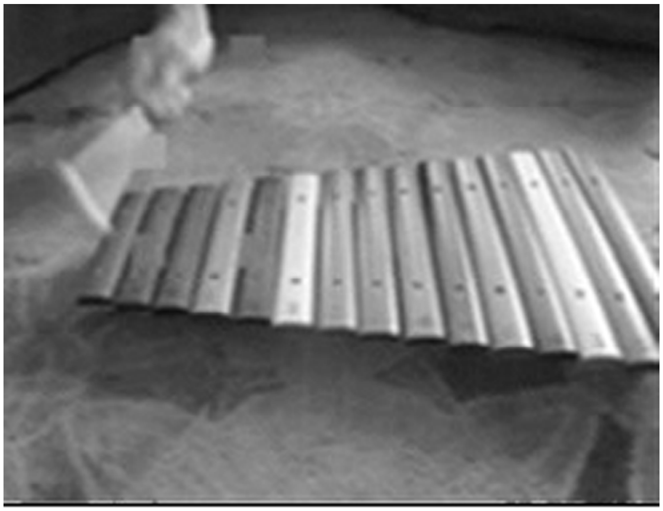

Figure 10: Proposed with Adaptive Method

Adaptive DT-CWT - SPIHIT compression using Diamond Search (DS) algorithm method is compared with existing DCT compression method and DT-CWT- SPIHIT. Meanwhile we compared Diamond Search (DS) algorithm with Exhaustive Search (ES) for comparative analysis. The Results are shown in table.1.

Figure 7-10 shows comparative results between proposed and existing methods. Figure 7 is the sample input video frame; these video frames are analyzed using existing DCT compression, DT-SPIHT without adaption and proposed DT-SPIHT with Adaption. The outcome of the test shows that ADT-SPIHT gives better CR and average PSNR value in all frames in compare to existing methodology. Table 1 shows the result for two different formats of videos. The results exhibit that compression ratio is improved in every frames. It was revealed in the experiments that in some instances, motion compensation actually reduces the reconstructed PSNR. Due to local expansions and contractions, most video sequences do not exhibit a one-to-one correspondence between pixels in consecutive frames. During temporal synthesis, the quantization error energy of some pixels will be mapped to multiple locations in the reconstructed frames, as a result of local expansions and contractions in the motion field, causing an increase in the overall frame distortion. Adding motion compensation into the transform can significantly increase its coding gain, it can also expand the quantization error energy. Motion vector blocks only go for compression; remaining block data's keeps their original pixel data, helps to improve CR. Without adaptive technique CR is significantly improved when compared with existing methodology. In our experiment mean adaptive weighting, helps to improve CR over both available existing models. We expect to obtain further improvements by adapting the spatial quantization and coding of the temporal sub-bands in the regions of expansion and contraction. Finally, it is important to consider the visual quality of the low temporal resolution frames. Without motion compensation, the low-pass frames contain disturbing ghosting artefacts. This is largely avoided by motion compensation with both motion models. We note that even when there is no increase in reconstructed PSNR, as with test sequence, the visual quality of the low-pass frames is still significantly improved.

5. CONCLUSION

The motion compensated diamond search algorithm using SDSP and LDSP for temporal wavelet decomposition of video sequences has been extended to incorporate SPIHT DT-CWT model. In many cases this leads to improved CR performance and visual quality in comparison to a block-based model. Future work will be directed at implementing superior motion models, and optimizing rate allocation for the motion information.

REFRENCES

[1] T. Pevný, and J. Fridrich, "Detection of double-compression in JPEG images for applications in steganography", *IEEE Transactions on Information Forensics and Security*, Vol. 3, No. 2, 2008, pp. 247-258.

[2] A. Khademi, and S. Krishnan, "Comparison of JPEG 2000 and other lossless compression schemes for digital mammograms", *Proceedings of 27th Annual International Conference of the Engineering in Medicine and Biology Society*, 2006, pp. 3771-3774.

[3] E. Soyak, S. A. Tsaftaris, and A. K. Katsaggelos, "Channel protection for H. 264 compression in transportation video surveillance applications. *Proceedings of 18th IEEE International Conference on Image Processing (ICIP)*, 2011, pp. 2237-2240.

[4] R. Schafer, "MPEG-4: a multimedia compression standard for interactive applications and services", *Electronics & communication engineering journal*, Vol. 10, No. 6, 1998, pp. 253-262.

[5] J. Korris, and M. Macedonia, "The end of celluloid: Digital cinema emerges", *Computer*, Vol. 35, No. 4, 2002, pp. 96-98.

[6] X. Wu, and N. Memon, "Context-based, adaptive, lossless image coding", *IEEE Transactions on Communications*, Vol. 45, No. 4, 1997, pp. 437-444.

[7] E. S. Carotti, J. C. De Martin, and A. R. Meo, Backward-adaptive lossless compression of video sequences", *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, 2002 Vol. 4, 2002, pp. IV-3417.

[8] N. D. Memon, and K. Sayood, “Lossless compression of video sequences”, *IEEE Transactions on Communications*, Vol. 44, No. 10, 1996, pp. 1340-1345.

[9] B. B. Chai, J. Vass, and X. Zhuang, “Significance-linked connected component analysis for wavelet image coding”, *IEEE Transactions on Image Processing*, Vol. 8, No. 6, 1999, pp. 774-784.

[10] F. Sheng, A. Bilgin, P. J. Sementilli, and M. W. Marcellin, “Lossy and lossless image compression using reversible integer wavelet transforms”, *Proceedings of International Conference on Image Processing*, 1998, pp. 876-880.

[11] A. R. Calderbank, I. Daubechies, W. Sweldens, and B. L. Yeo, “Wavelet transforms that map integers to integers. Applied and computational harmonic analysis, Vol. 5, No. 3, 1998, pp. 332-369.

[12] M. Grangetto, E. Magli, M. Martina, and G. Olmo, “Optimization and implementation of the integer wavelet transform for image coding”, *IEEE Transactions on Image Processing*, Vol. 11, No. 6, 2002, pp. 596-604.

[13] M. J. Weinberger, G. Seroussi, and G. Sapiro, “The LOCO-I lossless image compression algorithm: principles and standardization into JPEG-LS”, *IEEE Transactions on Image Processing*, Vol. 9, No. 8, 2000, pp. 1309-1324.

[14] X. Zhang, W. Wang, T. Yoshikawa, and Y. Takei, “Design of IIR orthogonal wavelet filter banks using lifting scheme”, *IEEE Transactions on Signal Processing*, Vol. 54, No. 7, 2006, pp. 2616-2624.

[15] Y. Zeng, L. Cheng, G. Bi, and A. C. Kot, “Integer DCTs and fast algorithms”, *IEEE Transactions on Signal Processing*, Vol. 49, No. 11, 2011, pp. 2774-2782.

[16] M. Johanson, “A scalable video compression algorithm for real-time Internet applications”, *Proceedings of 4th EURASIP Conference focused on Video/Image Processing and Multimedia Communications*, 2003, Vol. 1, pp. 329-334.

[17] Y. Cai, L. Mei, D. Wu, R. Zhao, L. Jia, and W. Wang, “Mobile Internet-Based Compression-Aware Scalable Video Coding-Rate Control for Enhancement Layers”, *Proceedings of Communications and Information Processing*, Berlin Heidelberg, 2012, pp. 741-746.

[18] J. Huang, K. Peng, C. Pan, F. Yang, and H. Jin, “Scalable Video Broadcasting Using Bit Division Multiplexing”, *IEEE Transactions on Broadcasting*, Vol. 60, No. 4, 2014, pp. 701-706.

[19] J. Y. Chen, C. W. Chiu, G. L. Li, and M. J. Chen, “Burst-aware dynamic rate control for H. 264/AVC video streaming”, *IEEE Transactions on Broadcasting*, Vol. 57, No. 1, 2011, pp. 89-93.

[20] U. Sadhvi Potluri, A. Madanayake, R. J. Cintra, F. M. Bayer, S. Kulasekera, and A. Edirisuriya, “Improved 8-point approximate DCT for image and video compression requiring only 14 additions”, *IEEE Transactions on Circuits and Systems I: Regular Papers*, Vol. 61, No. 6, 2014, pp. 1727-1740.

[21] D. R. Bhojani, and V. V. Dwivedi, “Innovative video compression technique using DWT-DCT”, *Proceedings of 1st International Conference on Emerging Technology Trends in Electronics, Communication and Networking (ET2ECN)*, 2012, pp.1-5.

[22] M. Thamarai, and R. Shanmugalakshmi, “Video coding technique using swarm intelligence in 3-d dual tree complex wavelet transform”, *Second International Conference on Machine Learning and Computing (ICMLC)*, 2010, pp. 174-178.

[23] J. K. Ahn, Y. J. Koh, and C. S. Kim, “Efficient fine-granular scalable coding of 3D mesh sequences”, *IEEE Transactions on Multimedia*, Vol. 15, No. 3, 2013, pp. 485-497.

[24] Fang, L. H., Feng, M. G., & Jie, X. H., “Images Compression Using Dual Tree Complex Wavelet Transform”, *Proceedings of International Conference on Information Science and Management Engineering (ISME)*, Vol. 1, 2010, pp. 559-562.